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Comment on "Macroscopic Resonant Tunneling of Magnetization in Ferritin"

In the recent Letter [1], Tejada *et al.* presented experimental results of zero-field cooled (ZFC) magnetization M_{ZFC} and hysteresis of ferritin. The authors concluded that their data showed strong departure from conventional behavior of thermally blocked particles and suggested quantum tunneling as an alternative explanation. One of their arguments is that they observed that for applied fields up to about 0.4 T, the temperature T_B at the maximum of M_{ZFC} increases with field, a feature which the authors claimed to be contrary to the case for simple superparamagnetic blocking. A similar increase of T_B with the applied magnetic field has earlier been observed for ferrofluids containing Fe_3O_4 [2] and $Fe_{1-x}C_x$ [3,4] particles with negligible interparticle interactions. We have shown [3] that the effect can be explained by superparamagnetic relaxation in a simple model where the nonlinear relation between the magnetization and the field is taken into account according to the Langevin function. We have applied this model to a system of particles with the properties of the ferritin particles in the paper by Tejada *et al.* We have used the values of the anisotropy constant $K = 2.6 \times 10^4\ \mathrm{J\,m^{-3}}$, the spontaneous magnetization $M_S = 4.7\ \mathrm{kA\,m^{-1}}$, and the average magnetic moment $m = 8.2 \times 10^{-22}\ \mathrm{A\,m^2}$ deduced from Tejada *et al.* [1], and an intrinsic relaxation time $\tau_0 = 10^{-12}$ s from Ref. [5]. In the calculations we included the effect of the anisotropy on the magnetization [6] and the effect of the field on the energy barrier E for magnetization reversal. We applied the relation $E = KV(1 - B/B_0)^\alpha$ for particles with a random orientation of easy axes, using the average switching field $B_0 = 0.958K/M_S = 5.3$ T [7], and $\alpha = 1.5$ [8]. V is the particle volume. By use of this model we found that the increase of T_B with the field, observed by Tejada *et al.*, may be reproduced if we assume that the magnetic moments of the ferritin particles are log normally distributed with a geometrical standard deviation, $\sigma = 1.4$. This distribution reflects the distribution of magnetic moments within the range of particle sizes 3.5 to 7.5 nm given by Tejada *et al.*, as well as the particle size distribution for ferritin in Ref. [9]. The values of T_B calculated for fields up to 0.6 T are shown in Fig. 1, together with the experimental data obtained by Tejada *et al.* As can be seen, the observed increase of T_B with the applied field may well be described with our simple model for superparamagnetic particles and thermal blocking. The observed decrease of T_B in fields above 0.4 T may be explained by other effects coming into play, because the Zeeman energy becomes comparable to the anisotropy energy. From these considerations we conclude that with respect to the field dependence of T_B, up to 0.4 T the experimental results of Tejada *et al.* are fully compatible with the behavior expected for particles that undergo simple superparamagnetic blocking and therefore give no evidence for macroscopic tunneling of the magnetization.

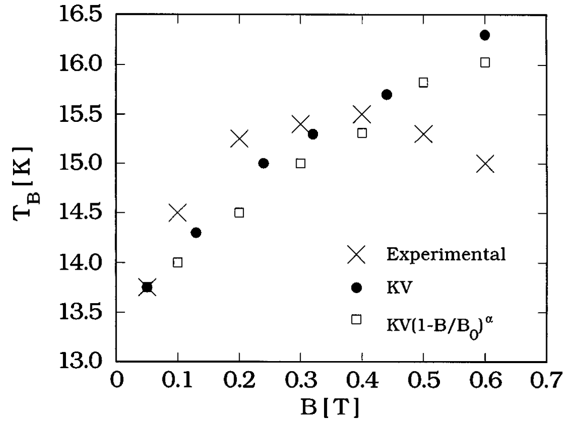

FIG. 1. The temperature T_B at the maximum of zero-field cooled magnetization vs applied field B. Comparison between calculated and experimental values. The data were calculated for a field independent energy barrier (filled circles) and for a barrier depending on field as described in the text (squares).

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